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(54) **METHODS OF FORMING CHARGE STORAGE STRUCTURES INCLUDING ETCHING DIFFUSED REGIONS TO FORM RECESSES**

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*H01L 29/792* (2006.01)  
(52) **U.S. CL.**  
CPC .... *H01L 27/11556* (2013.01); *H01L 21/32134* (2013.01); *H01L 27/11582* (2013.01); *H01L 29/66825* (2013.01); *H01L 29/66833* (2013.01); *H01L 29/7889* (2013.01); *H01L 29/7926* (2013.01)

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(58) **Field of Classification Search**  
CPC ..... H01L 27/115; H01L 27/11551; H01L 27/11521; H01L 27/11578  
USPC ..... 438/257, 261, 263, 26  
See application file for complete search history.

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(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.  
  
This patent is subject to a terminal disclaimer.

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**Related U.S. Application Data**

(63) Continuation of application No. 13/205,316, filed on Aug. 8, 2011, now Pat. No. 8,802,525.

(57) **ABSTRACT**

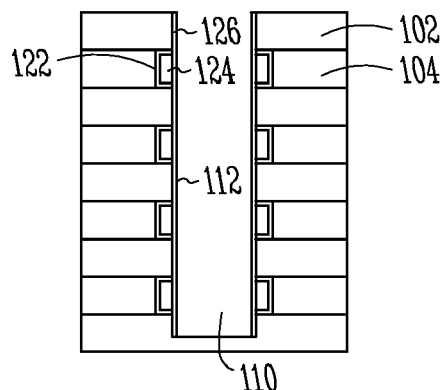
Methods are disclosed that include selectively etching diffused regions to form recesses in semiconductor material, and forming charge storage structures in the recesses. Additional embodiments are disclosed.

(51) **Int. Cl.**

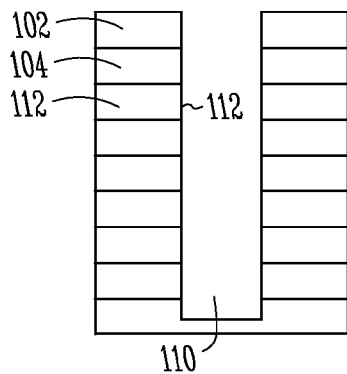
*H01L 21/336* (2006.01)  
*H01L 27/115* (2006.01)  
*H01L 21/3213* (2006.01)  
*H01L 29/66* (2006.01)

**19 Claims, 4 Drawing Sheets**

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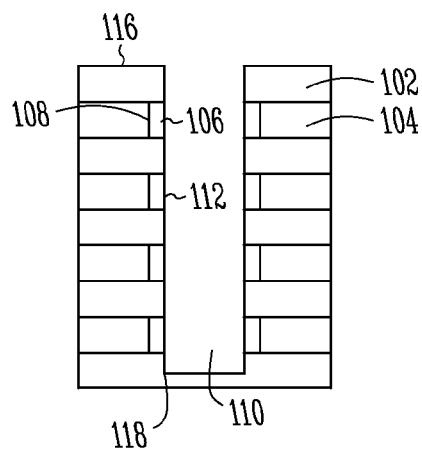


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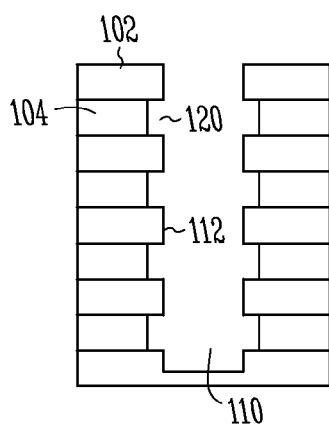
*Fig. 1A*

100



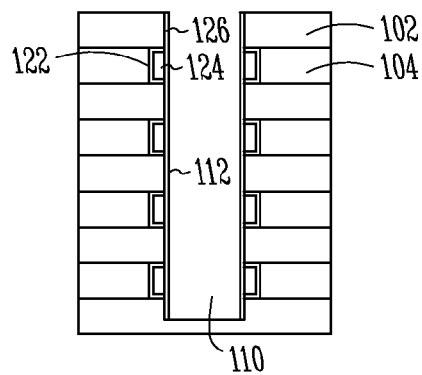
*Fig. 1B*

100



*Fig. 1C*

100



*Fig. 1D*

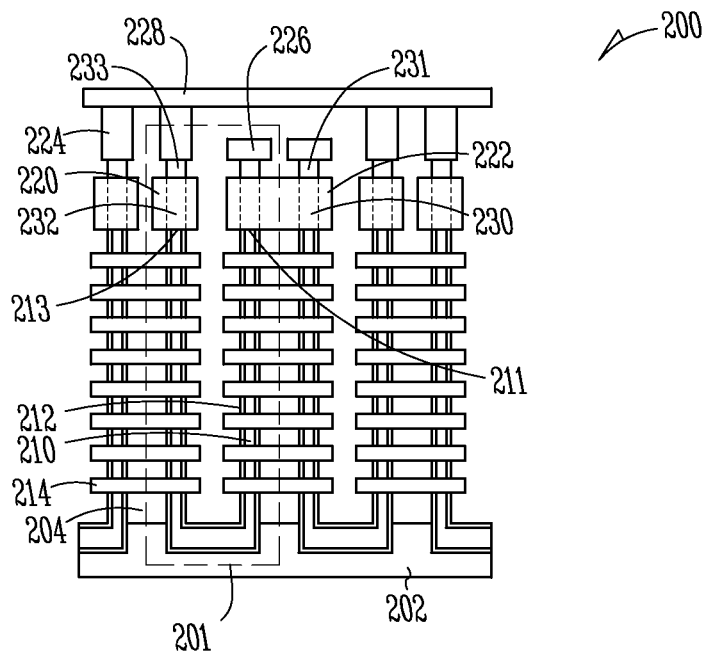


Fig. 2A

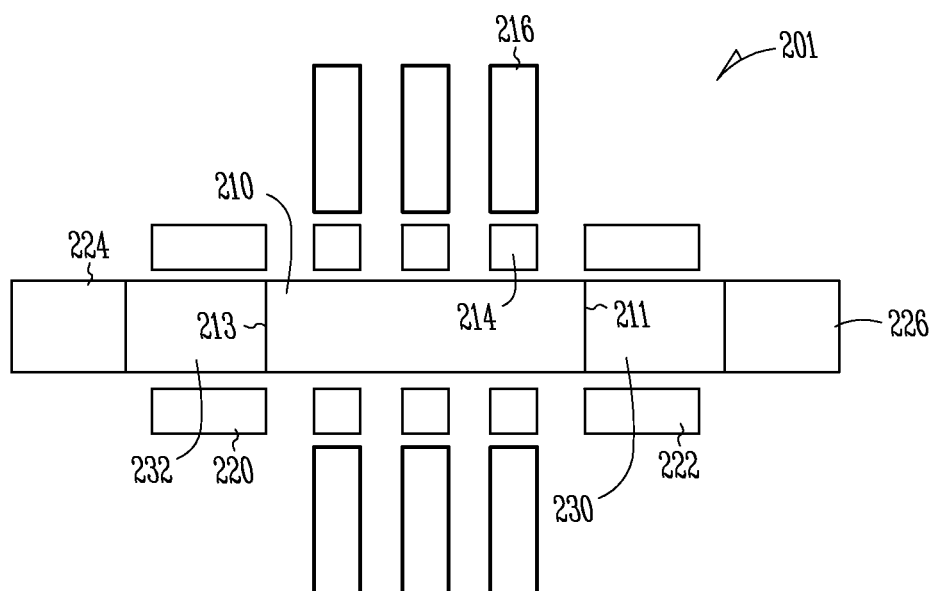
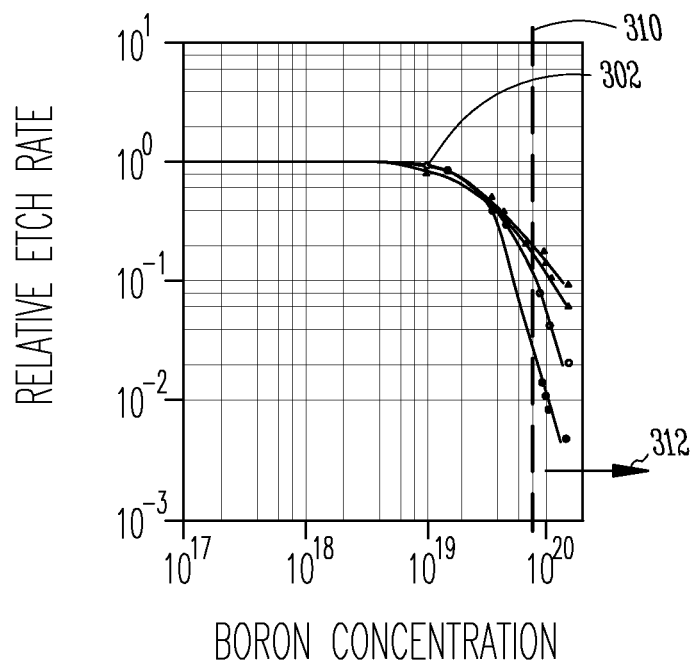
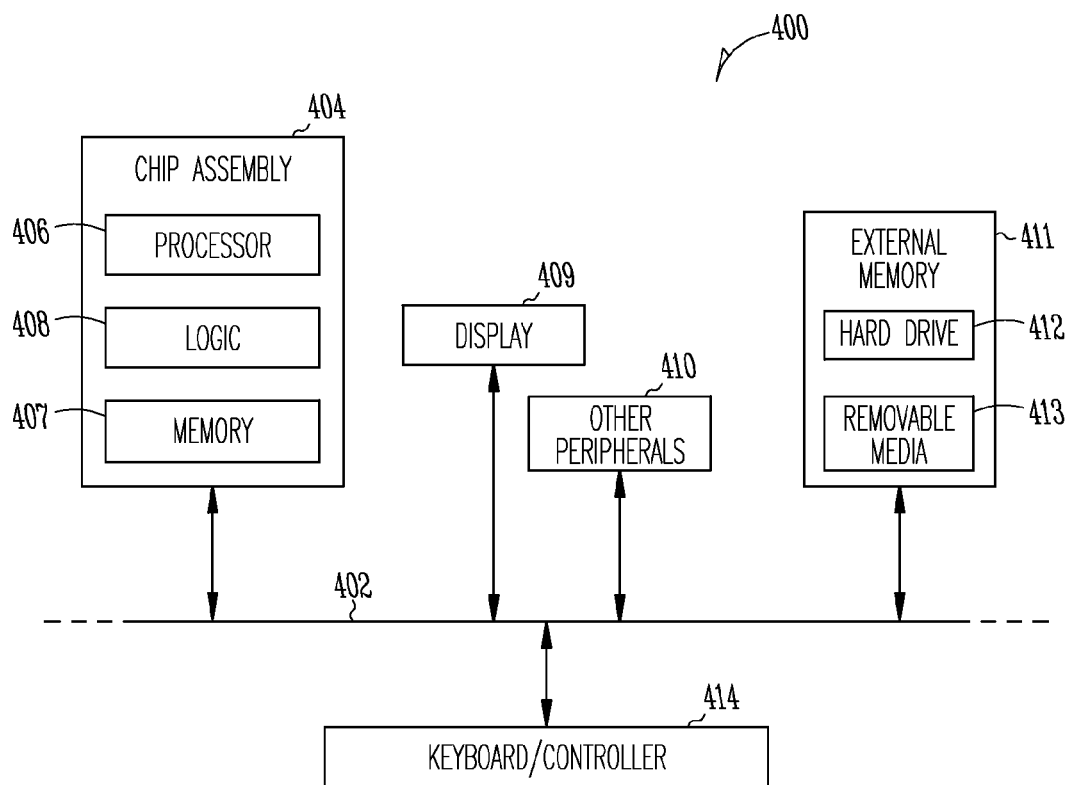


Fig. 2B

300 ↗



*Fig. 3*



*Fig. 4*

1

# METHODS OF FORMING CHARGE STORAGE STRUCTURES INCLUDING ETCHING DIFFUSED REGIONS TO FORM RECESSES

## PRIORITY APPLICATION

This application is a continuation of U.S. application Ser. No. 13/205,316, filed Aug. 8, 2011, which is incorporated herein by reference in its entirety.

## BACKGROUND

Higher memory density is always in demand to provide smaller devices with increased memory capacity. Forming memory devices laterally on a surface of a semiconductor chip uses a great deal of chip real estate. Improved memory devices are needed with new configurations to further increase memory density beyond what is available with traditional devices.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A-1D show process operations of forming a semiconductor device according to an embodiment of the invention.

FIG. 2A shows a memory device according to an embodiment of the invention.

FIG. 2B shows a block diagram of a portion of the memory device from FIG. 1A according to an embodiment of the invention.

FIG. 3 shows a graph of etch rate versus boron concentration according to an embodiment of the invention.

FIG. 4 shows an information handling system using a memory device according to an embodiment of the invention.

## DETAILED DESCRIPTION

In the following detailed description of the invention, reference is made to the accompanying drawings that form a part hereof and in which are shown, by way of illustration, specific embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. Other embodiments may be utilized and logical, electrical, material changes, etc. may be made.

The term “horizontal” as used in this application is defined as a plane parallel to the conventional plane or surface of a substrate, such as a wafer or die, regardless of the orientation of the substrate. The term “vertical” refers to a direction perpendicular to the horizontal as defined above. Prepositions, such as “on”, “side” (as in “sidewall”), “higher”, “lower”, “over” and “under” are defined with respect to the conventional plane or surface being on the top surface of the substrate, regardless of the orientation of the substrate. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the appended claims, along with the full scope of equivalents to which such claims are entitled.

FIG. 1A shows a substrate **100** including alternating materials. At least one dielectric material **102** is shown with at least one semiconductor material **104**. In one example, the dielectric material **102** includes silicon oxide. In one example, the semiconductor material **104** includes silicon, such as doped polysilicon. In one example, the polysilicon silicon is doped p-type. Acceptable p-type dopants include, but are not limited to boron, aluminum, gallium and indium. In one example, the

2

semiconductor material **104** is heavily doped (p+). In one example, the semiconductor material is doped to a concentration greater than approximately  $8 \times 10^{19}$  atoms/cm<sup>3</sup>.

An opening **110** having a sidewall **112** is shown in the substrate **100**. FIG. 1A shows a substantially vertical opening **110** for illustration, however in other examples, the opening **110** may be in a different orientation, such as horizontal. In the example shown, the substrate **100** includes multiple layers of alternating dielectric material **102** and semiconductor material **104**. In at least some embodiments, the dielectric material of the various dielectric material layers is the same dielectric material, and/or the semiconductor material of the various semiconductor material layers is the same semiconductor material, although different layers of dielectric material may comprise different dielectric materials and/or different layers of semiconductor material may comprise different semiconductor materials. The example stacked configuration may be useful to form specific devices, such as memory string devices, although the invention is not so limited. Other semiconductor structures will benefit from applying the methods described below.

FIG. 1B shows further processing of the substrate **100**. A diffused region **106** is shown formed into a semiconductor material **104**, with an interface **108** between the diffused region **106** and the semiconductor material **104**. In FIG. 1B, multiple diffused regions **106** are shown to form part of the multi-layer stack substrate. In one example, the diffused region **106** is diffused with n-type dopants. Acceptable n-type dopants include, but are not limited to phosphorous, arsenic, and antimony.

The diffusion mechanism of the n-type dopant into the semiconductor material **104** provides a number of useful features with respect to the diffused regions **106** and the opening **110**. Diffusion distance into the semiconductor portion **104** is substantially dependent on time, temperature, and concentration of a dopant source. Diffusion distance into the semiconductor material **104** is not substantially affected by aspect ratio or depth of the opening **110**. As a result, the diffused regions **106** extend a substantially identical distance into the semiconductor material **104** at the top **116** and the bottom **118** of the opening **110**. Although diffusion of an n-type dopant is used as an example, other dopants, such as p-type dopants, that provide etching selectivity are also within the scope of the invention.

In one example, phosphorous is used as the n-type dopant. One example of phosphorous diffusion includes furnace processing using phosphine as a phosphorous source. Another example of phosphorous diffusion includes furnace processing using POCl<sub>3</sub> gas as a phosphorous source. Another example of phosphorous diffusion includes deposition of a phosphorous doped material on an exposed surface of the semiconductor material **104**, and a subsequent anneal to drive the phosphorous into the semiconductor material **104**. Example materials to provide dopants to diffuse into the exposed surface of the semiconductor material **104** include phosphorous doped polysilicon, or phospho-silicate glass. Examples of deposition include chemical vapor deposition and pulsed laser ablation deposition.

FIG. 1C shows further processing of the substrate **100**. In FIG. 1C, the diffused regions **106** are removed through an etching process, leaving recesses **120**. Because the diffused regions **106** are n-type, and the semiconductor material **104** is p-type, the interface **108** serves as an etch stop. A number of etchant processes are available that are selective between n-type and p-type silicon. For example, a number of etchant processes are available that are highly selective between n-type and heavily doped p-type silicon. One example

includes wet etch processes. In one example, hydroxyl chemistry wet etch processes are used. One example of wet etch chemistry includes  $\text{NH}_4\text{OH}$  etchants. Another example of wet etch chemistry includes tetramethylammonium hydroxide (TMAH) etchants. Another example of wet etch chemistry includes potassium hydroxide (KOH) etchants. In embodiments where dopants other than n-type are used to form the interface **108**, an appropriate etchant is chosen with selectivity to the chosen dopant.

Attempting to etch a same doped semiconductor material **104** by itself presents a number of technical challenges. P+ doped silicon, for example, is difficult to etch at an appreciable rate using wet etch chemistries based on hydroxides.  $\text{HF}-\text{HNO}_3$  based chemistries can etch p+ doped silicon, however  $\text{HF}-\text{HNO}_3$  based chemistries are not sufficiently selective with respect to dielectrics such as silicon oxide. Plasma etch is sensitive to aspect ratio, such that a layer of material at the bottom **118** of the opening **110** may etch more slowly than a layer of material at the top **116** of the opening **110**.

In the processes of an embodiment of the present invention, diffusion of n-type dopants into the semiconductor material **104** is substantially insensitive to aspect ratio or depth within the opening **110**. Subsequent etchant chemistries, such as the example hydroxyl chemistries listed above, are available that are selective between n-type and p-type silicon, and selective with respect to dielectrics such as silicon oxide. As a result, the recesses **120** formed are substantially consistent in their distance into the semiconductor material **104** from a sidewall **112** of the opening **110** from the top **116** to the bottom **118** of the opening **110**.

FIG. 1D shows further processing of the substrate **100**. A first cell dielectric (e.g., a gate oxide) **122** is formed within the recesses **120**. A charge storage structure, such as a floating gate **124** or trap material, is then formed over the first cell oxide **122** in the recesses **120**. A second gate oxide **126** is then formed over the floating gate **124**. Consistently sized recesses **120** yield consistently sized charge storage structures (e.g., floating gates), and consistently sized charge storage structures provide consistent operating characteristics in memory devices. In subsequent process operations, an elongated channel region (not shown) may be formed within the opening **110** to form a memory string, such as a NAND memory string.

FIG. 1D shows the formation of floating gates **124** in the recesses **120**. In other examples, different charge storage structures may be formed within the recesses **120**. Another example of possible charge storage structures may include nitride trap layers (e.g., as part of an oxide-nitride-oxide structure).

As discussed above, memory devices are one type of semiconductor device that may be formed using the etching processes described. FIG. 2A shows an example memory device formed using the processes shown in FIGS. 1A-1D. FIG. 2A shows a dielectric **212** that substantially surrounds an elongated channel region **210**. A plurality of memory cell gates **214** are shown along the elongated channel region **210**, defining a plurality of memory cells. In one example, the memory cell gates **214** include floating gates, such as floating gates **124** from FIG. 1D. A first select gate **220** and a second select gate **222** are shown to selectively electrically couple the elongated channel region **210** to drain region **232** and a source region **230**, respectively. A dielectric **204** can fill in spaces between two or more of the components described above.

FIG. 2A shows an embodiment of a memory device **200** where the elongated channel region **210** forms a "U" shape with a pair of upward facing ends **211**, **213**. In one example,

a "U" shaped channel region is formed in a pair of openings, such as opening **110** from FIGS. 1A-1D, that are connected at their respective bottoms **118**. Another example configuration includes a linear, vertical, elongated channel region **210** with one end facing upward, and the other end facing downward. Embodiments with two upward facing ends, **211**, **213**, such as the substantially "U" shaped configuration, enable easier formation of some components at the ends **211**, **213** of the elongated channel region **210** during manufacture, compared to embodiments where components are formed deeper in the structure.

In one example, the elongated channel region **210** comprises n type semiconductor material, such as n-type polysilicon. A source region **230** and a drain region **232** are shown coupled to a first end **211** and a second end **213** of the elongated channel region **210**, respectively. In one example, the source region **230** and the drain region comprises p type semiconductor material, such as p-polysilicon. In operation, the pathway of source region **230**, to elongated channel region **210**, to drain region **232** acts as a p-n-p transistor, with select gates **220**, **222**, and memory cell gates **214** operating to allow, or inhibit signal transmission along the way. In the example shown, the source region **230**, elongated channel region **210**, drain region **232**, select gates **220**, **222**, and memory cell gates **214** collectively form a memory cell string **201**. In the example shown in FIG. 2A, each memory cell string **201** has a separate drain select gate **220**, while a source select gate **222** is shared between adjacent memory cell strings **201**.

A source line **226** and a data line, such as bitline **228**, are shown coupled to the source region **230** and the drain region **232** respectively. In one embodiment, a plug **224** is used to couple the bitline **228** to the drain region **232**. Each of the source line **226**, bitline **228** and plug **224** can comprise, consist of, or consist essentially of metal, such as aluminum, copper, or tungsten, or alloys of these or other conductor metals. As used herein, the term "metal" further includes metal nitrides, or other materials that operate primarily as conductors.

FIG. 2B shows a block diagram of memory cell string **201** from FIG. 2A. The elongated channel region **210** is shown, with a number of floating gates **214** and a number of control gates **216**. The select gates **220**, **222** are shown adjacent to the first end **211** and the second end **213** of the elongated channel region **210**.

FIG. 3 shows a graph **300** of etch rate versus boron concentration for an example wet etchant according to an embodiment of the invention. Potassium hydroxide as an etchant is illustrated in FIG. 3, however similar etch rate characteristics as a function of dopant concentrations are found with respect to other hydroxyl etchant chemistries.

FIG. 3 shows a marked change in etch rate at boron concentrations beginning at point **302** on the graph. At concentrations greater than about  $8 \times 10^{19}$  atoms/cm<sup>3</sup> shown at line **310** the etch rate for potassium hydroxide has dropped off significantly from the steady rate to the left of point **302**. As illustrated by the graph **300**, with boron concentrations greater than about  $8 \times 10^{19}$  atoms/cm<sup>3</sup> indicated by arrow **312**, potassium hydroxide does not significantly etch. This property provides selectivity between n-type and p-type materials, as described in relation to FIGS. 1A-1D above. This selectivity allows the interface between p-type and n-type materials to serve as an etch stop, where etching substantially stops. While some level of etching may continue to occur at an etch stop, because of the order of magnitude differences in etch rate (such as the example in FIG. 3), the etching is considered to have substantially stopped. In one example, the etch stop interface includes etch selectivity greater than approximately

5

20 to 1. The etch stop provides a process to form consistently-sized structures, such as floating gates, within high aspect ratio openings in devices such as vertical NAND memory devices.

In one specific example using TMAH, testing provided the following etch rate results.

Solution	temp (° C.)	Etch rate (μm/min)			
		1e21 B	3e18 B	1e15 B	3e14 P
TMAH 10:1	66		0.599		0.62
	78		0.833	0.598	0.84
	65	~0.0020			

The table confirms that heavily doped boron (for example  $1 \times 10^{21}$  atoms/cm<sup>3</sup> in the table) has a dramatic fall in etch rate.

An embodiment of an information handling system such as a computer is included in FIG. 4 to show an embodiment of a high-level device application for some embodiments of the present invention. FIG. 4 is a block diagram of an information handling system 400 incorporating a memory device 407 formed according to embodiments of the invention as described above. Information handling system 400 is merely one embodiment of an electronic system in which decoupling systems of the present invention can be used. Other examples of such systems include, but are not limited to, tablet computers, cameras, personal data assistants (PDAs), cellular telephones, MP3 players, aircraft, satellites, military vehicles, etc.

In this example, information handling system 400 comprises a data processing system that includes a system bus 402 to couple the various components of the system. System bus 402 provides communications links among the various components of the information handling system 400 and may be implemented as a single bus, as a combination of busses, or in any other suitable manner.

Chip assembly 404 is coupled to the system bus 402. Chip assembly 404 may include any circuit or operably compatible combination of circuits. In one embodiment, chip assembly 404 includes a processor 406 that can be of any type. As used herein, "processor" means any type of computational circuit such as, but not limited to, a microprocessor, a microcontroller, a graphics processor, a digital signal processor (DSP), or any other type of processor or processing circuit.

In one embodiment, a memory device 407 is included in the chip assembly 404. In one embodiment, the memory device 407 includes a NAND memory device formed according to embodiments described above. In one embodiment, the processor 406 and memory device 407 are formed on the same chip.

In one embodiment, additional logic chips 408 other than processor chips are included in the chip assembly 404. An example of a logic chip 408 other than a processor includes an analog to digital converter. Other circuits on logic chips 408 such as custom circuits, an application-specific integrated circuit (ASIC), etc. are also included in one embodiment of the invention.

Information handling system 400 may also include an external memory 411, which in turn can include one or more memory elements suitable to the particular application, such as one or more hard drives 412, and/or one or more drives that handle removable media 413 such as compact disks (CDs), flash drives, digital video disks (DVDs), and the like. A semiconductor memory die constructed as described in examples above is included in the information handling system 400.

6

Information handling system 400 may also include a display device 409 such as a monitor, additional peripheral components 410, such as speakers, etc. and a keyboard and/or controller 414, which can include a mouse, touch sensor, voice-recognition device, or any other user interface device that permits a system user to input information into and receive information from the information handling system 400.

While a number of embodiments of the invention are described, the above lists are not intended to be exhaustive. Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement that is calculated to achieve the same purpose may be substituted for the specific embodiment shown. This application is intended to cover any adaptations or variations of the present invention. It is to be understood that the above description is intended to be illustrative and not restrictive. Combinations of the above embodiments, and other embodiments, will be apparent to those of skill in the art upon studying the above description.

What is claimed is:

1. A method of forming a memory string, comprising: forming a stack of alternating layers of semiconductor material and dielectric material; forming an opening within the stack; diffusing a dopant into the semiconductor material exposed to the opening to form a plurality of diffused regions, each of the diffused regions extending a distance into the semiconductor material from a sidewall of the opening; selectively etching the diffused regions to form recesses in the semiconductor material, wherein etching substantially stops at each interface between the semiconductor material and the diffused regions; forming charge storage structures within the recesses; and forming a channel region within the opening.
2. The method of claim 1, further including coupling two adjacent channel regions together to form a "U" shaped channel region.
3. The method of claim 1, wherein forming an opening within the stack includes forming a vertical opening within the stack.
4. The method of claim 1, wherein forming charge storage structures within the recesses includes forming floating gates within the recesses.
5. The method of claim 1, wherein forming charge storage structures within the recesses includes forming nitride trap layers.
6. The method of claim 1, wherein diffusing a dopant into the semiconductor material includes diffusing a concentration of dopant atoms into a p-type semiconductor material at a concentration greater than  $8 \times 10^{19}$  atoms/cm<sup>3</sup>.
7. A method of forming a memory device, comprising: forming a number of memory strings, wherein forming the memory strings includes: forming a stack of alternating silicon and dielectric layers; forming an opening within the stack; forming a P-N interface within the opening in the stack with n-type regions being exposed within the opening; selectively etching the n-type regions to form recesses wherein etching substantially stops at the P-N interface; forming charge storage structures within the recesses; forming a channel region within the opening; and



7

coupling the number of memory strings together using source lines and data lines.

8. The method of claim 7, further including forming select gates associated with each memory string.

9. The method of claim 8, wherein forming select gates includes forming a source select gate and a drain select gate associated with each memory string.

10. The method of claim 7, wherein forming charge storage structures within the recesses includes forming floating gates within the recesses.

11. The method of claim 7, wherein forming charge storage structures within the recesses includes forming nitride trap layers.

12. The method of claim 7, wherein forming a stack of alternating silicon and dielectric layers includes forming a number of p-type silicon layers alternating with dielectric layers.

13. The method of claim 7, wherein selectively etching the n-type regions includes wet etching.

14. A method of forming an information handling system, comprising:

forming a number of memory strings, wherein forming the memory strings includes:

forming a stack of alternating silicon and dielectric layers;

forming an opening within the stack;

forming a P-N interface within the opening in the stack with selective etch regions being exposed within the opening;

8

selectively etching the selective etch regions to form recesses wherein etching substantially stops at the P-N interface;

forming charge storage structures within the recesses;

forming a channel region within the opening;

coupling the number of memory strings together using source lines and data lines; and

coupling a processor to the number of memory strings through the source lines and data lines.

15. The method of claim 14, wherein forming a P-N interface within the opening includes forming a P-N interface within the opening in the stack with n-type etch regions being exposed within the opening.

16. The method of claim 14, wherein forming a P-N interface within the opening includes forming a P-N interface within the opening in the stack with p-type etch regions being exposed within the opening.

17. The method of claim 14, wherein coupling a processor to the number of memory strings includes coupling a multi-core processor to the number of memory strings.

18. The method of claim 14, wherein forming a P-N interface within the opening includes diffusing an n-type dopant into a p-type layer.

19. The method of claim 18, wherein diffusing an n-type dopant into a p-type layer includes diffusing phosphorous into a boron doped layer.

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